

The Run II Luminosity Upgrade at the Fermilab Tevatron

Project Plan and Resource-Loaded Schedule

June 15, 2003

This document contains a summary of the project plan for the Run II Luminosity Upgrades at the Fermilab Tevatron. It addresses the principal action item from the DOE review of October 2002 by summarizing the resource-loaded plan for the upgrades. It includes References to previous and related documents, and also references to a set of Technical Notes to update the technical status of the projects in preparation for the follow-up review in July 2003.

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Executive Summary

The attached report describes the Run II Luminosity Upgrade at the Fermilab Tevatron. The goal of the upgrade program is to maximize integrated luminosity delivered to the CDF and DØ experiments, consistent with available resources, during the period prior to competitive physics results from the LHC experiments. It includes a resource-loaded plan of work for the luminosity upgrades and the major maintenance projects and a list of the major milestones for tracking progress and for decision points on scope.

The motivation and technical basis for the upgrade plan was first described in “Plans for Tevatron Run IIb”, presented to the Accelerator Advisory Committee in December 2001 (Ref. 1). The present document is based on the significant progress made since that time, both in modeling the performance of the upgraded accelerator complex and in planning the individual subprojects.

The upgrade plan is designed to deliver increasing luminosity in the short-term, while implementing and commissioning a program of upgrades to the accelerator complex to provide significant increases in the future. To achieve this, the upgrade must be well integrated with near-term operational planning, and with the plans for maintenance and increased reliability.

The plan for commissioning the Recycler and electron cooling, and integration into operations, is an important component of the Run II plan and is critical for meeting the schedule and luminosity performance goals. We are in the process of updating the Recycler commissioning plan. We will evaluate this new Recycler plan and its impact on the projections for integrated luminosity, and then incorporate it into a major update of the overall plan by the end of calendar 2003.

Based on the plan described in this document, we expect the integrated luminosity for FY 2004 to be in the range 0.25 to 0.38 fb⁻¹, with the lower number including the expected effects of Recycler commissioning work. This corresponds to doubling the size of the data sample existing at the end of this fiscal year. We will revise these estimates by October 1 based on better understanding of the Recycler plan. Our present estimate for the integrated luminosity for FY 2005 is the range 0.39 to 0.67 fb⁻¹.

1. Introduction

The goal of the Fermilab Run II Luminosity Upgrade Program is to maximize integrated luminosity delivered to the CDF and DØ experiments, consistent with available resources, during the period before the LHC experiments at CERN begin to produce competitive physics results. This plan represents Fermilab’s strategy for achieving that goal.

The motivation and technical basis for the upgrade plan are described in detail in “Plans for Tevatron Run IIb,” presented to the Accelerator Advisory Committee, December

2001 (Ref. 1). This plan was presented at the DOE Review in October 2002. The report from that review concluded that the technical tasks in the upgrade program are “adequate, reasonable, and in principle achievable” while some of the subprojects “represent significant challenge” and require R&D (Ref. 2). The principal action item from that review was the preparation by Fermilab of a “detailed, resource-loaded plan for completing the Run II luminosity upgrade” (Ref. 2). This document is a summary of the resource-loaded plan and outlines Fermilab’s path forward for Run II.

The principal elements of the plan were described in detail in Ref. 1, and were called out in Ref. 2. Significant progress has been made since that time, both in modeling the performance of the upgraded accelerator complex and in carrying out the individual subprojects. In preparation for an upcoming review, a set of Technical Notes is provided as an update on the status of the performance modeling and the subprojects.

In this document we summarize the current resource-loaded plan in Section 2 and the resulting projection for luminosity performance in Section 3. This plan will be updated as the projects progress. In particular, the Recycler commissioning plan is presently being re-evaluated, as described in section 1.5: Recycler Ring Stacking and Cooling. This re-evaluation will result in an update to the overall plan, which we expect to complete by December 2003. Although we show projections for luminosity incorporating the gains from Recycler operations, they are provisional.

The Run II physics program includes an extensive range of topics, from precision measurements that challenge the Standard Model to direct searches for new particles and forces (Refs. 3 and 4). Run II is now well under way with $\sim 245 \text{ pb}^{-1}$ of data accumulated through the end of May 2003 (Run I integrated $\sim 125 \text{ pb}^{-1}$) and new physics results are already emerging. This program at the Tevatron will continue to explore physics at the energy frontier until the LHC experiments produce physics results.

1.1 Performance Goals

“Stretch” and “base” goals were defined at the October 2002 DOE Review (Ref. 2: Table 2). In the October 2002 base goal, the integrated luminosity was to have reached 1.8 fb^{-1} per year by 2008. In the October 2002 stretch goal, the integrated luminosity was to have reached 3.0 fb^{-1} per year by 2007. In this document, an evaluation of the performance and schedule for the upgrades leads to the definition of new “design projection” (defined as using reasonable performance parameters and requiring reasonable improvements over past performance, but as not including scheduling contingency) and “base projection” (using conservative parameters and including schedule contingency) of ultimately 2.4 fb^{-1} per year and 1.2 fb^{-1} per year, respectively, which are discussed in section 2. Projected Luminosity Performance, below.

The present performance of the accelerator complex has achieved peak luminosities at the start of each store of $4.5 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$, and an integrated luminosity of 9 pb^{-1} per week (best achieved to date, May 2003). As shown in Table 1, the design presented here represents a factor of approximately 10 increase over the average May 2003 luminosity.

The luminosity at each experiment is given by the formula

$$L = \frac{\gamma}{2\pi} f_o B N_p N_{\bar{p}} \frac{H}{\beta^* \epsilon_p (1 + \epsilon_{\bar{p}} / \epsilon_p)}$$

where γ is the relativistic energy factor, f_o is the revolution frequency, N_p and $N_{\bar{p}}$ are the numbers of protons and antiprotons per bunch and B is the number of bunches of each. β^* is the beta function at the center of the interaction region, and ϵ_p and $\epsilon_{\bar{p}}$ are the proton and antiproton 95 percent normalized emittances. H is the hourglass form-factor due to the bunch lengths.

While the luminosity depends on the transverse emittances explicitly and on the longitudinal emittance through the hourglass form-factor, the most direct way to increase the luminosity is to increase the proton and antiproton bunch intensities.

The parameters in the luminosity formula are listed in Table 1, along with parameters defining the rate of antiproton production. The table compares the values for present operation with those projected for the completion of the upgrade program.

The principal contributions to the increase in luminosity are:

1. increase in the production rate of antiprotons and in the antiproton stack size
2. increase in the number of protons and the number of antiprotons per bunch

Planning for the Run II upgrades is based on achieving $2.9 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ peak luminosity, with an ultimate delivered integrated luminosity (per experiment) of approximately 55 pb^{-1} per week.

Parameter		May 03 Average	Run II Design	Ratio
Peak Luminosity	$\times 10^{31} \text{cm}^{-2} \text{sec}^{-1}$	3.7	29	7.8
Store hours per week		75	97	1.3
Store Duration	hr	15	15	1.0
Integrated Luminosity	pb^{-1}/wk	5.9	55	9.3
Number of Bunches		36	36	1.0
Protons/bunch	$\times 10^{10}$	22	27	1.2
Antiprotons/bunch	$\times 10^{10}$	2.2	13	5.9
β^*	cm	35	35	1.0
MI extraction Longitudinal Emittance	eV s	3.5	2.5	0.7
Bunch Length (rms)	m	0.6	0.5	0.9
Proton Transverse Emittance (at collision)	$\pi\text{-mm-mrad}$	20	18	0.9
Antiproton Transverse Emittance (at collision)	$\pi\text{-mm-mrad}$	18	18	1.0
Hourglass Form Factor		0.6	0.63	1.1
Pbar Transmission Efficiency	%	60	80	1.3
Stack Used	$\times 10^{10}$	134	583	4.4
Avg. Antiproton Production Rate	$\times 10^{10}/\text{hr}$	8.3	40	4.8

Table 1: Key parameters in the Run 2 luminosity performance. The upgrade design goal is compared to the average performance in May 2003 based on 22 stores.

1.2 Project Organization

The upgrade plan is to deliver increasing luminosity in the short-term, while implementing and commissioning a program of upgrades to the accelerator complex to provide significant increases in the future. To achieve this, the upgrade is well integrated with near-term operational planning, and with the plans for maintenance and increased reliability.

The near-term plans for increasing the luminosity were presented at the DOE review of October 2002, and are captured in a WBS system that extends through FY03. The upgrade summarized here extends this planning to the completion of the Run II Upgrades, in addition to the Maintenance Projects. To see a complete picture of the work in FY03, the Lab-wide WBS should also be added to the WBS described in this document. Beyond FY03 all the planned upgrade work is contained in the WBS described in this document.

The Run II Luminosity Upgrade Program consists of a set of subprojects. The program is managed from the Beams Division Headquarters Office with a project manager and technical coordinator. The project manager reports to the Beams Division Head, and hence to the Fermilab Associate Director for Accelerators and to the Laboratory Director. This is illustrated in Fig. 1.

The program consists of subprojects under two categories – Luminosity Upgrades and Maintenance Projects -- and is closely integrated with Run II Operations. The upgrade projects include all planned upgrades to the accelerator complex in support of Run II. The Maintenance Projects address the items identified in a vulnerability study in which component failures were identified which would result in significant down-time for the complex and loss of integrated luminosity for the experiments (Refs. 5 and 6). Run II Operations includes operation of the complex along with immediate maintenance and operational improvements.

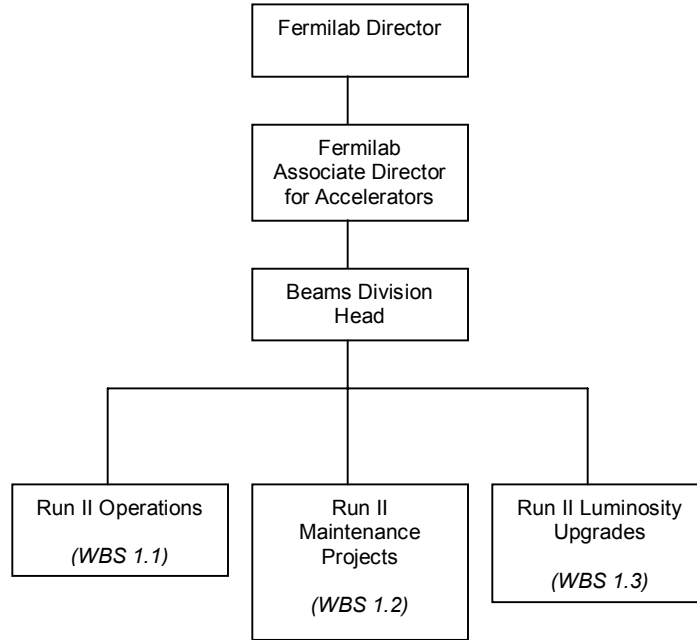


Figure 1: The Run II Organization.

While WBS 1.2 and 1.3 include all upgrades planned with a long-term view, there are many operational improvements in both reliability and performance, which occur along with accelerator operations under WBS 1.1. These improvements are developed in a short time frame in response to operational experience gained, and are not explicitly preplanned or captured under a WBS category (e.g. operating and learning to run better). As described in section 2.2, the resources for these improvements are included as a steady-state need based on recent operational experience.

The Luminosity Upgrades are organized in four main branches (level 3 in the WBS, see Table 2), with a leader for each branch. Each branch focuses on a particular aspect of the upgrade plan:

- 1.3.1 increasing the proton flux delivered to the antiproton production target
- 1.3.2 increasing the acceptance of antiprotons produced from the target
- 1.3.3 improving the stacking rate and stack size for antiprotons, and the transfers between machines
- 1.3.4 upgrading the Tevatron for operation at higher bunch intensities

Within the branches, each subproject (WBS level 4) has a leader. In many cases these project leaders are themselves department heads or group leaders in the Beams Division line management, so this project organization is integrated with the department organization.

Two of the level 3 branches have task forces assigned under a task force leader. These task forces, and their specific charges, are:

ANTIPROTON STACKING AND COOLING INTEGRATION

Model the performance of the integrated system, including the Debuncher, Accumulator, Recycler, and the transfers between these machines and to the Tevatron.

TEVATRON HIGH-LUMINOSITY OPERATION

Model the operation of the Tevatron with high bunch intensities, including beam-beam effects and instabilities.

These task forces will continue to develop the models throughout the project. The current status of this work is documented in Notes 1 and 2.

The work of the antiproton task force defines the phasing of the upgrade operations plan (as discussed in section 1.7), while the Tevatron task force work defines the scope of the upgrades to the Tevatron and the final luminosity performance.

The scope is reviewed and approved by the Beams Division Head, the Fermilab Associate Director for Accelerators, and the Fermilab Director.

WBS		WBS	
1	Run II		
1.1	Operations		
1.2	Maintenance Plan		
1.3	Luminosity Upgrades		
1.3.1	Protons on Pbar Target		
1.3.1.1	Slip Stacking	1.3.4	Tevatron High Luminosity
1.3.1.2	Pbar Target and Sweeping	1.3.4.1	Tevatron Task Force
1.3.1.3	Main Injector Upgrades	1.3.4.2	Beam-beam Limitations
1.3.2	Pbar Acceptance	1.3.4.3	Active Beam-Beam Compensation
1.3.2.1	Lithium Lens Upgrades	1.3.4.4	Increased Helix Separation
1.3.2.2	AP2 and Debuncher Acceptance	1.3.4.5	Luminosity Leveling
1.3.3	Pbar Stacking and Cooling	1.3.4.6	Improved Control and Diagnostics
1.3.3.1	Stacking & Cooling Integration T.F.	1.3.4.7	Tevatron Vacuum Improvements
1.3.3.2	Debuncher Cooling	1.3.4.8	Tevatron Alignment
1.3.3.3	Stacktail Cooling	1.3.5	Shutdown Schedule
1.3.3.4	Recycler Stacking and Cooling	1.3.6	Project Management
1.3.3.5	Electron Cooling	1.3.6.1	Management Oversight
1.3.3.6	Rapid Transfers	1.3.6.2	Project Milestones

Table 2: Subprojects at project WBS level.

1.3 Principal Elements of the Operations Subproject

The principal elements of the ongoing support for operations are defined within the laboratory's WBS. Included are routine maintenance activities required to keep accelerator equipment in operational condition, and incremental improvements aimed at improving reliability and maximizing performance of the accelerator complex as currently configured. Examples of activities supported in this area include:

- Maintenance of all electrical and mechanical devices/systems in the accelerator complex.
- Minor projects aimed at improved reliability and performance of operating systems.
- Maintenance and improvements to RF, instrumentation, and controls systems.
- Materials purchases of cryogenics required for Tevatron operations.
- Control room support for accelerator operations.
- Accelerator physics support for operations.

1.4 Principal Elements of the Maintenance Plan

Major vulnerabilities within the accelerator complex were identified in a study completed in the summer of 2002 (Ref. 5). These are components or component classes identified as having the potential for interrupting operations within the accelerator complex for more than 3 months in the event of failure. The list of 44 components and/or component classes so identified was subsequently evaluated and prioritized resulting in the first seventeen items requiring attention as listed in Table 4.

Since completion of the vulnerabilities report, the situation within the upstream end of the linac (the drift tube portion) has deteriorated. The solution to the power tube vulnerability identified in the report (expansion of the spares inventory) has proved difficult to achieve due to the inability of the vendor to deliver tubes. Whether this is a permanent or transitory situation is yet to be determined. A task force has been established to develop both short and long term strategies. Possible long term responses range from reestablishment of our vendor as a reliable source of tubes, to the procurement of a new, klystron powered, drift tube linac. The range of costs associated with these responses ranges from the \$1.5 M listed on the first line of Table 4 for 7835 Amplifier Tubes, to up to \$40 M for a new linac. It is unlikely we will know which response is appropriate before the fall 2003.

Two prototype RF cavities for the Booster (Table 4) will be installed during summer 2003. Depending on the operating experience, it will be determined whether the additional 17 cavities and upgraded high power RF systems will be built to complete the installation.

1.5 Principal Elements of the Luminosity Upgrade Plan

All elements of the upgrade plan are identified in the Work Breakdown Structure (Table 2). Each of the principal elements is summarized briefly in the following paragraphs. The relationship of these elements to the operation phases is shown in Table 5 and Fig. 4. Many of the subproject elements have been ongoing for many years and the remaining scope of work is being picked up by the Luminosity Plan in Calendar Year 2003.

SLIP STACKING IN THE MAIN INJECTOR

(Notes 3 and 4)

Slip stacking seeks to double the proton intensity delivered to the antiproton production target by combining two Booster batches into one batch in the Main Injector. An extensive beam study program has been very successful at low beam intensities (Note 3). The main issue is beam-loading of the RF at high intensities. A plan to compensate for this beam loading is being developed and the electronics is being designed (Note 4).

UPGRADE TO THE ANTIPROTON TARGET STATION

(Note 5)

Two upgrades will reduce damage to the antiproton target with the higher beam flux delivered by slip-stacking. The first is the use of Inconel alloys instead of nickel for the

target material itself. The R&D program is well advanced and has demonstrated that these alloys are more resilient to local heating. The second is to sweep the beam across the target, compensating with reciprocal sweeping of the secondary beam downstream of the target. The sweeping magnets have been built and the upstream magnet is presently installed in preparation for testing with beam.

LITHIUM LENS UPGRADE

(Note 6)

The original goal for the lithium lens design was operation at a gradient of 1000 T/m. In order to increase operational reliability, lenses are currently operated at 750 T/m, resulting in a reduction in antiproton acceptance of about 10-15 percent. Even at this lower gradient, each lens typically survives for only about one year of operation. Improvements in lens fabrication have already been implemented and are expected to lead to more reliable operation. An improved design is being tested in a prototype program. It is expected that this new design will allow reliable operation at higher field gradient, increasing antiproton production by of order 10 percent.

AP2 AND DEBUNCHER ACCEPTANCE

(Note 7)

The AP2 beamline transports the antiprotons from the target and lithium lens to the Debuncher ring. The combined admittance of AP2 and the Debuncher is significantly smaller than the original design specification. The goal of this subproject is to locate the limiting apertures and correct them, through realignment, improvements in beam steering, or by rebuilding components. While the initial scope of this project is well defined, including beam studies and documenting the beamline layout, the full scope of actions will be developed over the next year as the elements limiting the aperture are identified.

UPGRADE OF THE DEBUNCHER AND ACCUMULATOR COOLING SYSTEMS

(Note 8)

The cooling systems in the Debuncher and Accumulator rings will be upgraded to allow a higher stacking rate. These upgrades will be implemented in two phases.

In the initial subproject phase the Debuncher system will be improved to allow an initial repetition rate of about 1.8 seconds (compared to the present 2.2 seconds). (The repetition rate will later be increased to 2.0 seconds when the Main Injector supports slip-stacking and NUMI operation.)

In the second subproject phase, the addition of a new 4-8 GHz band in the stack tail cooling system will significantly improve the system capability at high stacking rates. The full utilization of this upgrade requires that large stacks be stored in the Recycler Ring using Electron-Cooling, and that partial-stacks of antiprotons are transferred from the Accumulator to the Recycler every 30 minutes in an optimized transfer called "Rapid Transfers". These companion upgrades are described below.

RECYCLER RING STACKING AND COOLING

(Reference 8)

In the updated strategy, the RR plays a key role in antiproton stacking to very large stack sizes. By transferring small stacks frequently from the Accumulator to the Recycler, the stack tail system in the Accumulator can be optimized for stacking rate. In order to cool the very large stacks anticipated, the RR includes both conventional stochastic cooling systems and an electron cooling system.

The RR is fully described in Ref. 8. Commissioning is underway and was expected to be completed by the end of FY03. It has been delayed due to vacuum-related problems which will be addressed during the summer shutdown in 2003. As a result the initial commissioning continues. In the overall upgrade plan, the initial RR commissioning must be completed by the time the electron cooling is installed in summer 2004.

Commissioning of the combined system then continues with integration into the rest of complex in early 2005.

ELECTRON COOLING

(Note 9)

The implementation of electron cooling will allow very large antiproton stacks accumulated in the Recycler Ring to be transferred to the Tevatron with small longitudinal emittance. The initial phase of the project is well advanced. This includes an R&D program at the Wide Band Laboratory for the development of a system to produce an electron beam with the specific characteristics required. At the completion of this phase, the system will be moved into the RR and commissioning will begin on cooling the antiproton beam.

RAPID TRANSFERS

(Note 10)

At present small stacks are transferred from the Accumulator to the Recycler periodically to support commissioning of the Recycler Ring. The transfers require manual tune-up of the transfer beam lines and typically interrupt stacking for about one hour. Once Electron Cooling is implemented in the RR, and the Accumulator Upgrade has been completed, it will be necessary to transfer a partial-stack every half hour. A transfer time of less than one minute will be achieved by automating the transfer process, which will require upgrades to the beam line instrumentation, improvements to the power supply regulation, and feedback from the Main Injector damper system.

ACTIVE BEAM-BEAM COMPENSATION IN THE TEVATRON

(Note 1 section 01b)

Two approaches are being pursued to achieve active compensation for the effects of beam-beam interactions. Because of long-range beam-beam effects, the tune shifts are different for each bunch. An R&D program has been under way for some time to study the use of an “electron lens” to actively compensate for beam-beam tune shifts bunch by bunch. One device has been built and tested. The full compensation scheme requires two electron lenses. After further studies and development a decision will be made on constructing a second electron lens. Beam-beam compensation using pulsed wires has been proposed for the LHC. An initial study of the applicability of this approach to the

Tevatron has started, and a decision will be made on whether to pursue a parallel R&D program. Each of these decision points is called out in the project schedule.

INCREASED HELIX SEPARATION IN THE TEVATRON

(Note 1 section 01c)

Long-range beam-beam effects due to near-misses of proton and antiproton bunches on their helical orbits can lead to significant tune shifts. In general these tune shifts decrease as the second power of the orbit separation, so an increase in this separation can significantly reduce the beam-beam effects. A study is under way of methods to increase the separation between the proton and antiproton helical orbits by increasing the field in the electrostatic separators and by adding additional separators. It is expected that significant improvements can be made. Even before additional or increased performance separators are available, considerable progress can be made by altering the optics to smooth the existing helix.

1.6 Scope Reduction

We have reviewed the scope of the program following the October 2002 DOE review, and made the following changes.

1. plans for operating the Tevatron with 132 nsec bunch spacing rather than the present 396 nsec spacing have been abandoned
2. while the Recycler Ring plays a central role in antiproton stacking, plans for recycling the antiprotons remaining at the end of each Tevatron store have been abandoned

132 NSEC OPERATION

(Reference 7)

With the experience gained in Run II and with simulations of the proposed detector upgrades for Run IIb, the CDF and DØ experiments determined that they can accept a higher number of interactions per crossing, up to an average of ~ 10 interactions per crossing, without significant loss in performance. This allows a peak luminosity of about $4 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ at 396 nsec bunch spacing (36 bunches each of protons and antiprotons)¹. This removes the primary motivation for increasing the number of bunches to $\sim 100 \times 140$ in the Tevatron.

132 nsec operation would require three times the total number of protons in the Tevatron, significantly increasing beam-beam effects, and the introduction of a crossing angle at the interaction points. This crossing angle reduces the integrated luminosity by about 40 percent and introduces concern about synchro-betatron resonances.

An initial assessment indicated that significant work is needed to design and build the crossing angle regions, to upgrade the instrumentation, and to study the beam-beam

¹ A design guideline/ground rule for the collider detector upgrades was that they demonstrate capability of handling a luminosity of 2×10^{32} , and also demonstrate operating margin at 4×10^{32} , both at 396 nsec bunch spacing. This was documented in September 2002 in the DØ Run IIb Upgrade TDR and the CDF IIb Detector TDR.

effects and possible instabilities. With the original motivation no longer pressing, 132 nsec operations have been dropped from the project scope.

Should the experiments find that their triggers or event reconstruction are adversely affected at very high luminosities, luminosity leveling will be implemented by varying β^* to limit the maximum luminosity delivered in the early part of a store. In a parametric model of Tevatron stores (Note 1), luminosity leveling at $2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$ reduced the integrated luminosity by only 10 percent. It is very likely that the experiments will be able to exceed this luminosity, so this is a worst-case scenario.

ANTIPROTON RECYCLING

(Reference 8)

The original concept for recycling the unused antiprotons at the end of each Tevatron store requires first that the protons be removed from the Tevatron by scraping, after which the antiprotons are decelerated and extracted back through the Main Injector into the Recycler Ring.

Using the parametric model for Tevatron operations (Note 1), it is estimated that about 75 percent of antiprotons will be remaining at the end of store, but due to the larger emittance only about 70 percent of these will be accepted back into the Recycler. Also, historically about 70 percent of stores end without unexpected loss of the beams, so one might expect that recycling would contribute, on the average, about 35-40 percent of the Tevatron antiproton stack into the Recycler, with a similar contribution to the luminosity. However, much of this loss of luminosity can be recovered by increasing the store length and allowing more time for antiproton stacking. For the stacking rate planned, the difference in integrated luminosity with and without recycling is only about 10 percent.

The major technical obstacle to recycling is the removal of the protons prior to antiproton deceleration and extraction. This must be accomplished quickly (so as not to significantly add to shot setup time) and reliably, without risking Tevatron quenches or significant radiation dose for the experiment detectors. Initial studies have indicated that meeting these requirements is problematic, and would require substantial work and study time.

It has been decided that no work will be scheduled for recycling at this time. The Recycler Ring will be used as an added stage for accumulating antiprotons from the Antiproton Source. If the antiproton stacking rate cannot be increased as expected, the contribution to luminosity from recycling could be more significant and recycling could be reconsidered.

1.7 Phases of Operation

We have developed a detailed Work Breakdown Structure and “bottom-up” Resource-Loaded Schedule for the projects as described in section 2. The phased introduction of the upgrades, and their contribution to the increase in luminosity, results from this schedule.

The operating scenario is characterized in five phases as the upgrades are introduced. Dates for the start of each phase are included here and also in Table 5.

PHASE 1 - PRESENT

The initial phase of the upgrade program extends the current FY03 plan for Run II, with upgrades to the Antiproton Source to allow reduced cycle time, completion of damper systems in the MI and improvement to the helical orbits in the Tevatron. The BPM systems (Beam Position Monitors) will be upgraded throughout the complex and component alignment improved in the Antiproton Source and Tevatron. Operational improvements will focus on reducing the emittance growth during shot setup, and increasing the proton and antiproton transfer efficiency.

PHASE 2 – DECEMBER 2004

With the introduction of Slip-stacking and the first part of the AP2 and Debuncher Acceptance upgrade, the antiproton stacking rate increases to the limit of the present Stacktail cooling system (about 22×10^{10} per hour peak). Stack sizes are limited by the Accumulator cooling (250×10^{10}). This phase maximizes the antiproton production capability with the present stacking scheme.

PHASE 3 – FEBRUARY 2005

With the introduction of the Recycler Ring and electron cooling, the mode of operation for the complex is quite different. The antiprotons are loaded from the Recycler, rather than from the Accumulator, into the Main Injector and then into the Tevatron. During the initial commissioning of this phase, the high energy physics program will be supported by the Accumulator, reducing disruption to the experiments.

With the stack transferred to the Recycler, larger stack sizes will be possible, although stacking rate will continue to be limited by the Stacktail cooling in the Accumulator.

PHASE 4 – NOVEMBER 2005

Once the physics program is supported from antiproton stacks in the Recycler, and the new mode of operation is established, the Stacktail cooling system in the Accumulator is upgraded to allow significantly higher stacking rates. Small stacks of antiprotons are then transferred from the Accumulator to the Recycler every half hour.

PHASE 5 – MAY 2007

The AP2 and Debuncher acceptance will be increased throughout the period of these upgrades, with major realignment or replacement of components occurring during each of the scheduled shutdowns. All major component replacements will be completed by the end of the 2006 shutdown.

The helix separation will be increased initially in phase 1 with an optimization of the use of the existing hardware, and again in phase 5 with the introduction of additional electrostatic separators. The present R&D program on active compensation for beam-beam induced tune shifts will be evaluated in FY04, and if successful will result in the fabrication of a production system for phase 5. These upgrades will allow stable Tevatron operation with significant increases in the bunch intensities. During phase 5a, the luminosity continues to increase with time as beam studies, commissioning, and learning continue. Phase 5b represents operations at the ultimate luminosity for stable data accumulation for the experiments.

2. Resource-Loaded Schedule

Most of the subprojects are fully specified and resource estimates are made from designs or concepts. For a few other subprojects, their developmental nature does not allow the full scope to be defined accurately at this time. In these cases an estimate of the scale of the work is included in the schedule, and branch points are identified where the scope will be defined.

At this time, the scope cannot be fully defined for the AP2 and Debuncher Acceptance project (1.3.2.2). The limiting apertures must first be identified and then corrected through alignment and fabrication of replacement beam elements. In this case, the project scope is currently estimated with a representative cost and effort (with 100 percent contingency). This estimate will be improved as the project progresses.

The plan for commissioning the Recycler and electron cooling, and integration into operations, is an important component of the Run II plan and is critical for meeting the schedule and luminosity performance goals. A set of commissioning parameters and requirements has been developed and the commissioning plan is presently being updated. The schedule includes milestones for the evaluation of the plan and of commissioning progress, and a protocol for introducing these systems into operations.

We will review the upgrade plans for the Tevatron to address beam-beam effects in September 2003. The final design for increasing the helix separation (1.3.4.4), and progress on the R&D for active compensation (1.3.4.3) will be evaluated, and the estimates in the schedule improved if necessary.

In all three cases above where the scope is not yet fully defined, representative estimates are included in the work plan with adequate contingency, and decision points are included in the schedule. Other than these specific areas, the subproject scope and the work breakdown are fully defined.

2.1 Methodology

The leader of each subproject defines the Work Breakdown Structure for the subproject to an appropriate sub-level for management of the subproject, typically to level 6. For each task the duration is estimated and dependence on other tasks identified. The M&S cost is estimated, and labor resource needs estimated as named individuals wherever possible, or by generic labor category if specific individuals have not yet been identified. Beam study shifts are also assigned as a resource.

Access to the accelerator tunnels is required for some specific tasks. It is assumed that access periods of one day can be scheduled into normal operations, along with maintenance work. Any tasks needing more than one day of access are scheduled during the shutdowns defined in the Fermilab Long Range Schedule. These shutdowns are indicated in Figs. 4 and 5.

Cost estimates are entered in FY2004 dollars.

A quality of estimate flag is assigned to each task indicating the confidence in the estimation (for both labor and M&S cost). These flags are interpreted in the following way:

- a) engineered concept, or vendor information – 20 percent contingency
- b) initial conceptual design, experience with similar projects – 40 percent contingency
- c) experience with other projects – 60 percent contingency
- d) scope not yet fully defined, use an estimate of the cost scale – 100 percent contingency

This contingency is rolled-up to WBS level 1, and is then globally redistributed by fiscal year, weighted towards the later years, rather than following the individual subproject M&S or labor cost profiles exactly.

Labor is calculated in work-days, with a full-time equivalent (FTE) defined as 221 work-days per year, allowing for 15 percent vacation, holidays, and sick time. Labor costs are calculated using the current average SWF costs for each labor category, scaled up by 4 percent to correct for salary increases to 2004.

Resource leveling was applied to ensure that particular individuals are not over-committed and that resource availability is consistent with ongoing operations and work on other Beams Division projects, including NUMI and SY120.

The plan is constrained by available M&S funding in FY03 and the expected funding level for FY04. This results in deferring some maintenance items until FY05-FY07, and delays some of the early work on the luminosity upgrade by about three months.

2.2 Cost and Labor Summary

Table 3 itemizes the Materials and Services (M&S) costs and the Labor costs at WBS Level 4 for the Luminosity Upgrades, WBS 1.3, summed over the duration of the program. The contingency applied at the task level rolls up to a total contingency of 45 percent in M&S and 47 percent for Labor.

M&S ESTIMATE

Table 4 shows the M&S costs for Maintenance and Reliability. The first section of the table updates the major vulnerability items identified in Table 3 of Ref. 6, updating the status in the present plan. The costs listed in this table are included in Table 3.

The total M&S cost for the Luminosity Upgrades, WBS 1.3, is shown in Fig. 2 as a function of fiscal year. As described above the contingency is weighted towards later years. To satisfy funding constraints in FY03 and FY04 some of the early procurements for the luminosity upgrade are delayed. This in turn delays the implementation of operations phase 1 of the upgrades by about four months. It is also necessary to delay or defer maintenance projects, as described in Table 4. The result is that mitigation of vulnerabilities identified in Ref. 6 is delayed.

LABOR ESTIMATE

The labor profile for WBS 1.2 and 1.3 is shown in Fig. 3, with a breakdown by type of work. The labor is actually assigned to named individuals wherever possible within the categories listed in the figure. The total work is shown per fiscal year, without contingency, in units of FTE. The actual peak labor need during FY04 is over 110 FTE. The increase in labor from FY03 to FY04 is accounted for by manpower becoming available as the elements of the earlier FY03 upgrade plan are completed.

The estimates are “bottom-up” and take into account the dependence on expertise shared with ongoing operations and between projects and are based on recent Run II experience. Nevertheless the interpretation of labor contingency, which is estimated to be 47 percent, should include both additional labor resources and stretching-out of task durations. This is reflected in the allocation of M&S and labor contingency costs to later years and in schedule contingency included in phase milestones (see Schedule Milestones section and Table 5).

OPERATIONS SUPPORT

Based on the experience with Run II for the last two years, we estimate that the ongoing accelerator operations support (WBS 1.1) requires a steady state level of about 360 FTE. This includes operations itself, regular short-term maintenance and repairs, and short-term (but continuous) development of operational improvements. While many of these improvements, such as reducing the mis-matches between beamlines and accelerators, contribute over the long-term to a steady increase in luminosity performance, they are not explicitly captured in this WBS. Typically they arise and are addressed on a weekly or monthly basis as a result of current operating experience.

There is a sufficient number of personnel within the Beams Division to meet the needs of both the ongoing operational support and the upgrade and maintenance WBS. However, there may be a challenge in matching available expertise to the required tasks..

There are two primary issues for the labor resources:

1. Specific experts are shared between the WBS projects and operational responsibilities – this is taken into account to some extent in the bottom-up estimates which are based on the current availability of this expertise. Nevertheless overloading the existing experts with both operational and project responsibilities is a concern for schedule contingency.
2. Some specific skills are oversubscribed within the Beams Division, including expertise in beamline optimization, electrical engineering, control system programming and instrumentation. This is addressed by supplementing the Beams Division personnel with personnel from the other divisions at Fermilab and with help from other institutions. Currently there are about 20 FTE from outside the Beams Division contributing to both this WBS and the FY03 WBS, and we expect this number to increase over the next few months.

CONSISTENCY WITH THE FY04 BUDGET GUIDANCE

The profile contained in Fig. 2 has been constrained to provide consistency with the currently projected FY2004 Fermilab budget based on the President's Budget Request. The available funding for Run II activities is roughly \$6M short of what was anticipated as the Run II Plan was initially conceived. The major modifications to the plan to accommodate the FY2004 budget are as follows:

- Deferral of the expansion of the Beams Division staff by 20 people (partially mitigated by greater utilization of laboratory resources outside the BD).
- Deferral of a number of maintenance and vulnerability items beyond 2004 (as noted in Table 4).
- Phase funding of procurements in support of the stack-tail upgrade.

It is difficult to quantify the impact of these actions in terms of integrated luminosity over either the short or the long term. The primary impact is on the degree of confidence that can be assigned to the luminosity projections.

The Run II Luminosity Upgrade at the Fermilab Tevatron

(S\$K)		Labor			M&S		
		Estimate	Cont	Total	Estimate	Cont	Total
1	Run II	19,816	9,602	29,417	14,058	6,443	20,501
1.2	Maintenance and Reliability	1,150	716	1,866	3,404	1,458	4,862
1.3	Luminosity Upgrades	18,665	8,886	27,551	10,654	4,986	15,639
1.3.1	Protons on Pbar Target	1,200	539	1,739	1,672	642	2,313
1.3.1.1	Slip Stacking	311	111	421	650	230	880
1.3.1.2	Pbar Target and Sweeping	117	52	168	97	37	133
1.3.1.3	Main Injector Upgrades	773	376	1,150	925	375	1,300
1.3.2	Pbar Acceptance	2,586	1,400	3,986	2,036	1,267	3,303
1.3.2.1	Lithium Lens Upgrades	596	260	856	673	320	993
1.3.2.2	AP2 and Debuncher Acceptance	1,990	1,140	3,130	1,363	947	2,310
1.3.3	Pbar Stacking and Cooling	4,455	2,160	6,615	2,254	1,028	3,282
1.3.3.1	Stacking and Cooling Integration	463	93	556	0	0	0
1.3.3.2	Debuncher Cooling	23	14	36	0	0	0
1.3.3.3	Stacktail Cooling	774	313	1,088	1,171	468	1,639
1.3.3.4	Recycler Stacking and Cooling	780	466	1,246	0	0	0
1.3.3.5	Electron Cooling	1,009	491	1,500	566	252	818
1.3.3.6	Rapid Transfers	1,406	783	2,189	517	308	825
1.3.4	Tevatron High Luminosity	8,222	3,907	12,129	4,692	2,049	6,741
1.3.4.1	Tevatron Task Force	2,536	1,014	3,550	0	0	0
1.3.4.2	Beam-beam Limitations Active Beam-Beam	858	437	1,295	0	0	0
1.3.4.3	Compensation	1,449	805	2,254	1,385	741	2,126
1.3.4.4	Increased Helix Separation	1,104	386	1,490	1,747	462	2,209
1.3.4.5	Luminosity Leveling	13	7	20	0	0	0
1.3.4.6	Improved Control and Diagnostics	861	491	1,352	1,240	684	1,924
1.3.4.7	Tevatron Vacuum Improvements	13	5	18	90	36	126
1.3.4.8	Tevatron Alignment	1,388	762	2,150	230	126	356
1.3.5	Shutdowns	0	0	0	0	0	0
1.3.6	Project Management	2,201	880	3,082	0	0	0

Table 3: M&S costs for Luminosity and Reliability Upgrades at WBS Level 4.

The Run II Luminosity Upgrade at the Fermilab Tevatron

Area	Dec 2002 White Paper				
	Component	Cost	Updated M&S Cost	M&S Cont	Status or Plan
Linac	7835 Amplifier Tubes	\$1.5M	\$1.6M	60%	FY03-6
Linac	F1123 Switch Tubes	\$200K	-		completed FY03
Linac	New Quadrupole Power Supplies	\$1.0M	-		maintain existing supplies
Linac	Water System Rebuild	\$500K	-		completed FY03
Booster	Orbit Bump Magnets	\$1M	\$150K	40%	FY04 + labor in WBS – Table 3.
Booster	Low Level RF	\$100K	\$100K	40%	FY05
Booster	High Power RF	\$7.5M	-		Defer
Booster	RF Accelerating Cavities	\$10M	-		Defer
Main Injector & Beamlines	Dipole PS Transformers	\$150K	\$150K	40%	FY04
Main Injector & Beamlines	Quad PS Transformers	\$80K	\$80K	40%	FY04
Main Injector	Kicker Magnet Vacuum Tubes	\$500K	\$50K	40%	FY04 – found spares & vendor
Tevatron Low Beta	PS Magnetics	\$30K	\$30K	40%	FY04
Tevatron Cryogenics	Centrifugal Cold Compressors	\$100K	\$100K	40%	FY04
Site Infrastructure	345-KV Switchgear KRS	\$200K	\$200K	20%	FY06
Site Infrastructure	345-KV Switchgear MSS	\$300K	\$300K	20%	FY06
Site Infrastructure	345-KV MSS Transformer	\$1.2M	-		Defer
Site Infrastructure	Harmonic Filter Damping Resistors	\$20K	\$20K	20%	FY04
Other Major Maintenance Items					
Tevatron	Replace Tevatron Magnet Stands		\$324K	40%	FY03-5
Tevatron	Correct Tevatron dipole coil sag		Labor only		FY03-4

Table 4: Principal Elements of the Maintenance Plan (Refs. 5 and 6).

The Run II Luminosity Upgrade at the Fermilab Tevatron

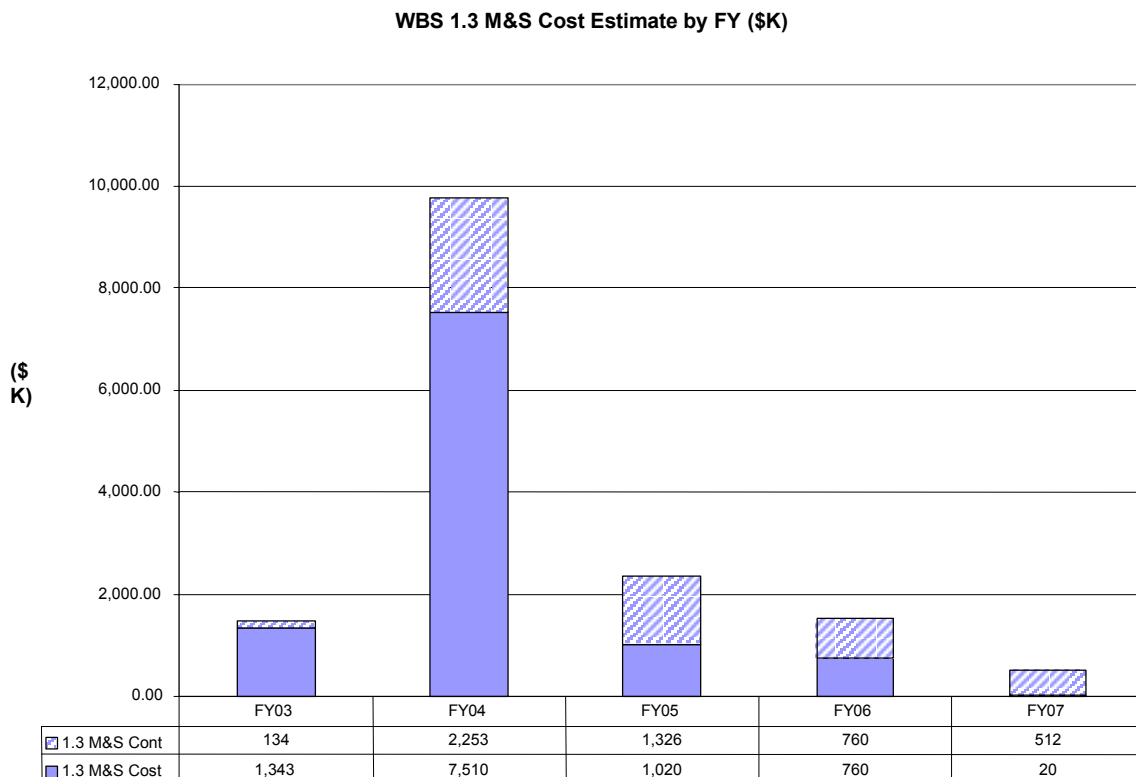


Figure 2: M&S Costs by fiscal year for the Luminosity Upgrades, WBS 1.3.

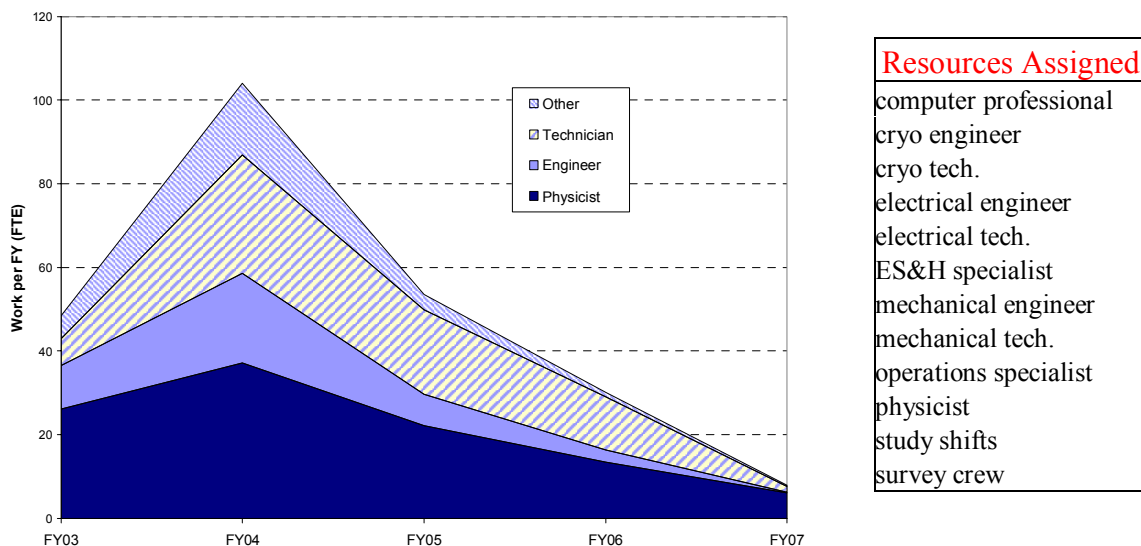


Figure 3: Labor profile (without contingency) for WBS 1.2 and 1.3, by work type, showing the work per fiscal year in units of FTE. The project WBS starts in January 2003, so FY03 includes only three quarters.

2.3 Schedule Milestones

Milestones are included in the schedule at completion of each subproject, and at the transition between the phases described above. Schedule contingency is included explicitly in the milestones for the introduction of each operating phase. These milestones, with estimates of schedule contingencies, are listed in Table 5.

A representation of the schedule at WBS Level 4, with the milestones, is shown in Fig. 4. A breakout at the lower WBS levels would show well over 600 individual tasks, each with resources assigned.

Milestone		Date	with Contingency	Principal Upgrade
1.6.2	Project Milestones	09/29/03		
1.6.2.1	Review: Tevatron Upgrade Plan	09/29/03		
1.6.2.2	Review: RR & e-Cooling Commissioning	12/16/03		
1.6.2.3	Review: Phase 2-4 Transition Plan	04/16/04		
1.6.2.5	Start Phase 2 Operations	12/14/04	04/15/05	Slip Stacking
1.6.2.6	Start Phase 3 Operations	02/22/05	08/25/05	RR & e-cool
1.6.2.7	Start Phase 4 Operations	11/17/05	04/06/06	Stacktail & Rapid Transfers
1.6.2.8	Start Phase 5 Operations	05/23/07	09/24/07	Final Acceptance & Helix completed

Table 5: Primary Milestone Dates for Luminosity Upgrades.

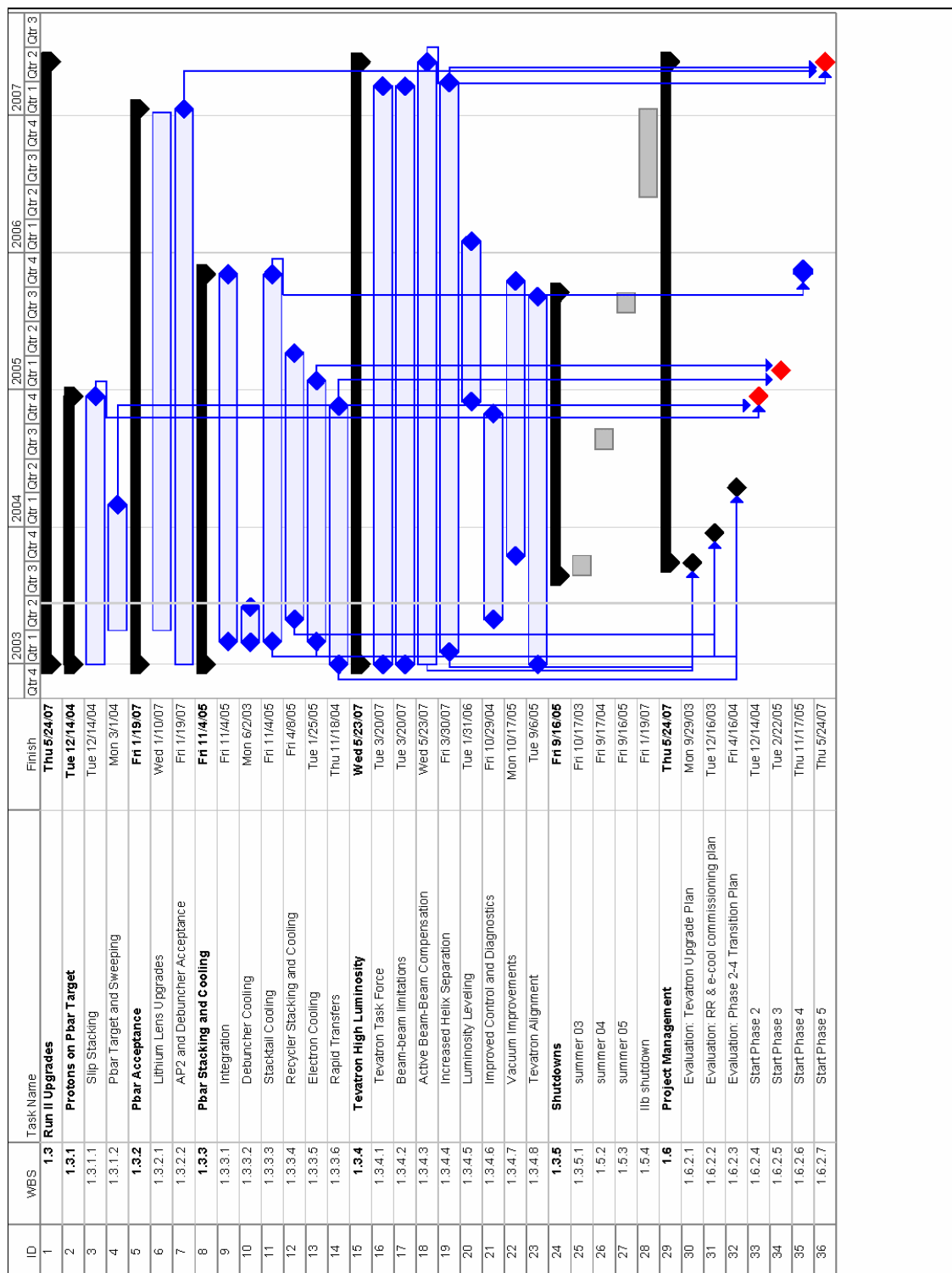


Figure 4: Schedule Summary and Milestones for Luminosity Upgrades

3. Projected Luminosity Performance

We have simulated antiproton production and Tevatron stores using the parametric models described in Notes 1 and 2. The models simulate operation of the accelerator complex and predict the luminosity achievable with the design parameters for the upgrades. These parametric models have been benchmarked against both data and detailed calculations, and are further used to determine the sensitivity of the performance to key parameters. This in turn is used to gauge the uncertainty of the luminosity projection.

The results of this modeling are combined with the project and shutdown schedules derived from the Resource-Loaded Schedule. Realistic ramp-up in performance is included after each shutdown and with the introduction of each new phase of the upgrades. Operational interruptions are included based on recent operating experience.

3.1 Luminosity Parameters

There are three classes of parameters in the estimating the luminosity.

1. Performance parameters determine the luminosity performance in a single store. These include antiproton stacking rate, transfer efficiencies, and bunch intensities.
2. Operating scenario parameters define operating efficiency and include the amount of time scheduled for HEP rather than studies and maintenance, down time due to Tevatron quenches, and equipment failure. These parameters are summarized into one parameter, the average number of store hours per week.
3. Learning rates when new upgrades are introduced, and recovery rates after each scheduled shutdown

Class 1 parameters are determined from the upgrade specifications and the parametric models, benchmarked to either data or calculations.

For the average store hours per week, we use the average achieved for the period Feb-May 2003. During this period there were several unscheduled interruptions to HEP, as well as weeks with high efficiency operation. We consider this to be a good representation of long-term running. In fact, with the emphasis on long-term maintenance, we anticipate improvement in these parameters. However, no credit is taken in luminosity estimates for such improvement until the completion of the upgrades, at which point amount of time scheduled for studies is reduced.

Class 3 parameters are estimated from Run II experience in recovering from scheduled shutdowns.

3.2 Luminosity Projection

Two models are considered in the luminosity projection. The first is the “Design Projection,” and the second is the “Base Projection.” The meaning of these terms is defined below.

Design Projection

1. uses the design performance parameters for the upgrade projects (design margin, above the design performance parameters, is included in the specifications for the subprojects)
2. assumes improvement in the HEP store hours in the last phase of the upgrades
3. does not include added schedule contingency

Base Projection

1. uses conservative performance parameters that the upgrade projects are likely to exceed
2. does not assume improvements in HEP store hours per week
3. includes explicit schedule contingency for bringing upgrades online (see Table 5)

The parameters for each phase are shown for the design projection in Table 6. In this table the final phase of the upgrades, phase 5 is considered in two parts. The first part, 5a, includes study shifts for commissioning the final stages of the upgrade. In the second part there are no longer study shifts required for upgrades, although maintenance study shifts continue to tune-up accelerator operation.

A comparison of the parameters for the design and base projections in phase 5b is included in Table 7.

The luminosity projections are summarized in Fig. 5, which shows the weekly integrated luminosity in pb^{-1} for the design and base projections, and in Table 8, which lists the integrated luminosity per fiscal year. We anticipate that executing the commissioning plan for the Recycler Ring will consume antiprotons and reduce the annual integrated luminosity for FY04 by up to 60 pb^{-1} . This reduction is not included in Table 8. Estimates beyond FY05 depend upon completion of the Recycler commissioning and electron cooling R&D.

The Run II Luminosity Upgrade at the Fermilab Tevatron

Operating Phase	1	2	3	4	5a	5b	
Phase Commissioning Starts	current phase	12/14/04	2/22/05	9/13/05	1/16/07	12/11/07	
Luminosity Parameters							
Initial Luminosity	68.0	90.5	136.7	218.0	294.0	294.0	$\times 10^{30} \text{cm}^{-2} \text{sec}^{-1}$
Integrated Luminosity per wk	10.9	13.9	20.5	31.4	50.3	55.3	pb^{-1}
Integrated Luminosity per store	2.3	2.9	4.2	6.5	8.3	8.3	pb^{-1}
Number of stores per wk	4.8	4.8	4.8	4.8	6.1	6.7	
Average Store Hours per wk	70	70	70	70	88	97	Hours
Tevatron Parameters							
Number of Protons per bunch	240	240	240	240	270	270	$\times 10^9$
Number of Pbars per bunch	36.3	44.9	67.8	108.1	129.6	129.6	$\times 10^9$
Proton Emittance	18	18	18	18	18	18	$\pi\text{-mm-mrad}$
Pbar Emittance	18	18	18	18	18	18	$\pi\text{-mm-mrad}$
Transfer Eff. To Low Beta	0.75	0.75	0.75	0.75	0.8	0.8	
Antiproton Parameters							
Zero Stack Stacking Rate	18.0	26.2	26.2	40.3	46.1	46.1	$\times 10^{10}/\text{hour}$
Average Stacking Rate	12.0	14.9	22.4	35.8	40.2	40.2	$\times 10^{10}/\text{hour}$
Stack Size transferred	174.3	215.4	325.4	518.9	583.2	583.2	$\times 10^{10}$
Protons on Target (PoT)	5	8	8	8	8	8	$\times 10^{12}$
Pbar Production per PoT	17.0	20.0	20.0	28.0	32.0	32.0	$\times 10^{-6}$
Pbar cycle time	1.7	2.2	2.2	2	2	2	sec

Table 6: Design Projection parameters for each operating phase.

The Run II Luminosity Upgrade at the Fermilab Tevatron

Parameter	Design	Base	
Luminosity			
Initial Luminosity per store	294.0	160.5	$\times 10^{30} \text{cm}^{-2} \text{sec}^{-1}$
Integrated Luminosity per week	55.3	26.5	pb^{-1}
Integrated Luminosity per store	8.3	4.9	pb^{-1}
Number of stores per week	6.7	5.5	
Average Store Hours per week	97	79	Hours
Tevatron			
Number of Protons per bunch	270	250	$\times 10^9$
Number of Pbars per bunch	129.6	76.4	$\times 10^9$
Proton Emittance	18	18	$\pi\text{-mm-mrad}$
Pbar Emittance	18	18	$\pi\text{-mm-mrad}$
Transfer Eff. To Low Beta	0.8	0.75	
Antiproton			
Zero Stack Stacking Rate	46.1	31.5	$\times 10^{10}/\text{hour}$
Average Stacking Rate	40.2	25.3	$\times 10^{10}/\text{hour}$
Stack Size transferred	583.2	366.7	$\times 10^{10}$
Protons on Target (PoT)	8	7	$\times 10^{12}$
Pbar Production per PoT	32.0	25.0	$\times 10^{-6}$
Pbar cycle time	2	2	sec

Table 7: Parameters for the design and base projections for phase 5b (completion of the upgrade program).

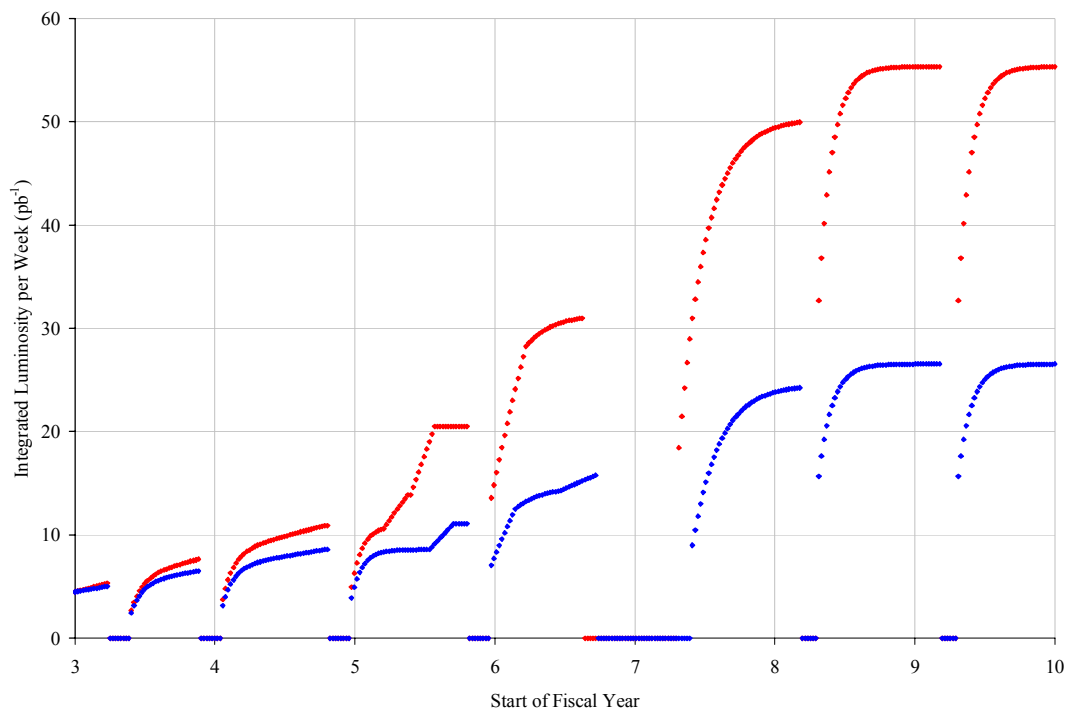


Figure 5: Weekly integrated luminosity for the design projection (red/upper) and base projection (blue/lower).

	Integrated Luminosity (fb ⁻¹)			
	Design Projection		Base Projection	
	per year	Accum- ulated	per year	Accum- ulated
FY03	0.22	0.30	0.20	0.28
FY04	0.38	0.68	0.31	0.59
FY05	0.67	1.36	0.39	0.98
FY06	0.89	2.24	0.50	1.48
FY07	1.53	3.78	0.63	2.11
FY08	2.37	6.15	1.14	3.25
FY09	2.42	8.57	1.16	4.41

Table 8: Integrated Luminosity in fb⁻¹ for Design and Base Projections. Entries beyond FY05 are based on successful integration of the Recycler with electron cooling.

Upon completion of the upgrade plan, the annual integrated luminosity is 2.4 fb^{-1} for the Design Projection and 1.2 fb^{-1} for the Base. These compare to 3.0 fb^{-1} and 1.8 fb^{-1} for the stretch and base goals of the October 2002 review. Compared to the previous stretched goal, Fig. 5 indicates a slower pace of implementing the individual upgrade components, also leading to reduced accumulated luminosities in Table 8. These changes result from the following improvements in understanding the projections:

- inclusion of the Fermilab long-range shutdown schedule to accommodate detector installations
- improved performance modeling
- bottom-up resource-loaded schedule
- removal of 132 nsec and recycling from the project scope
- delays in Recycler commissioning

3.3 Performance Risks and Mitigation

In achieving the design luminosity, three risks have been identified: failure to meet performance parameter goals, major technical and schedule risks, and gradual schedule creep.

PERFORMANCE PARAMETERS

The sensitivity of the luminosity projection to the parameter values used in the design projection (phase 5 in Table 6) is approximated by the formula below, in which L is the integrated luminosity in pb^{-1} per week (or per year), R is the antiproton stacking rate in $10^{10}/\text{hr}$, S is the stack size in 10^{10} antiprotons, E is the antiproton transfer efficiency, and P is the number of protons per bunch in the Tevatron $\times 10^{10}$.

$$\frac{\Delta L}{L} = 0.3 \frac{\Delta R}{R} + 0.6 \frac{\Delta S}{S} + 0.9 \frac{\Delta E}{E} + 0.7 \frac{\Delta P}{P}$$

The parameters R and S determine the length of the typical store. While the formula neglects the correlation terms between the variables, nevertheless it provides a good representation of the change in luminosity performance as the parameters are varied.

For the base projection we have chosen what we consider to be a conservative set of parameters with a high probability that they can be exceeded.

MAJOR SCHEDULE AND TECHNICAL RISKS

There is schedule risk in the completion of the Recycler commissioning. This commissioning was expected to be completed at the end of FY03. By the end of the January 2003 shutdown, problems with the vacuum system impaired further progress. Limited access to the tunnel hampered our ability to address these problems in a timely manner, resulting in schedule slippage. Necessary rework will be accomplished during the summer 2003 shutdown.

Based upon data with the repaired Recycler, we will re-evaluate the commissioning plan. The updated plan will be incorporated into the overall Resource Loaded Schedule by December 2003.

We started in 1995 to develop electron cooling for antiprotons at Fermilab, to allow stacking to very large stack sizes. While electron cooling has been successful in lower-energy applications, this will be the first application at high beam energies. The R&D program is progressing extraordinarily well (see Note 9). Nevertheless, the final performance of this scheme carries technical risk. Two lower level milestones (not further discussed in this document) are defined where the project will demonstrate performance that lowers this risk. The first is on 3/19/04 with the establishment of the performance of the complete electron beam itself, and second, on 1/25/05, with the successful cooling of the antiproton beam in the Recycler.

The Recycler is required to meet a specific performance level by summer 2004 in order to commission electron cooling. We have included a six-month contingency in the phase milestones, which introduces this same contingency into the base luminosity projection in recognition of the uncertainty in both the Recycler commissioning and completion of the electron cooling R&D.

We are studying a fall-back scenario in which the Recycler and electron-cooling are not integrated into operation. It does not allow the full upgrade of the stacktail system, since the stack remains in the Accumulator, but the other upgrade projects would be completed. This scenario leads to an integrated luminosity which is close to the base projection.

SCHEDULE CREEP

The most likely sources of schedule creep are from sharing particular expertise between this WBS and ongoing operations, and limitations imposed by budget constraints.

Expertise sharing is largely addressed with the bottom-up approach used in the scheduling, and in the schedule contingency applied to the base projection. It will be further addressed as all labor resources are named and additional personnel are added from outside Beams Division.

The known and expected budget constraints of FY03 and FY04 have been imposed on the schedule. Milestones have been defined to facilitate progress tracking. The schedule will be evaluated on a continuous basis and benchmarked quarterly, with progress and financial reports to the Associate Director for Accelerators. He will also chair monthly meetings of the Project Management Group.

4. Conclusion

As summarized in this report we have:

- developed a resource-loaded plan for the luminosity upgrades, combined with the major maintenance projects
- improved modeling of performance, which combined with schedule provides design projection
- established milestones for tracking progress and for scope decision points
- defined a strategy to maximize the luminosity and hence the scientific potential of Run II at the Fermilab Tevatron.

5. References

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<http://www-bd.fnal.gov/doereview02/>
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3. Exploring the Universe with the Fermilab Proton-Antiproton Collider, the CDF and DZero collaborations, 10 December 2002.
<http://www-bd.fnal.gov/reviews/references/Orbach-Dec2002-sent.doc>
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http://www.fnal.gov/directorate/program_planning/HEPAP_P5_Response.pdf
5. Fermilab Accelerator Chain Vulnerabilities, T. Dombeck, 9/11/02.
http://www.fnal.gov/directorate/program_planning/VulRept.doc
6. Accelerator Improvements to Support Run II Goals, Fermilab Directorate, December 13, 2002.
http://www-bd.fnal.gov/doereview03/docs/AI_Support_RunII.pdf
7. Report to the Fermilab Director Concerning 132 Nanosecond Operation During Run 2, 6 June 2002. <http://www-bd.fnal.gov/doereview02/Team132Report.pdf>
8. Fermilab Recycler Ring Technical Design Report, November 1996, (Revision 1.2). <http://www-lib.fnal.gov/archive/1997/tm/TM-1991.html>
(In multiple sections to facilitate downloading)

6. Update – Technical Notes

Ref. 1 includes detailed motivation and technical description for many of the subprojects. The following documents are provided as an update on recent progress and plans. They can be accessed at <http://www-bdnew.fnal.gov/doereview03/Current> or individually, as referenced below. These are working documents, which we expect to be updated as needed. Readers should be careful to check the document date and to use the current versions, which are always available for downloading.

Performance Models

1. Tevatron Modeling, and Accelerator Physics, M. Syphers, *editor*, May 28, 2003 (due to its length, this Note has been divided into 4 files, denoted 01a... through 01d... to facilitate downloading).

http://www-bdnew.fnal.gov/doereview03/Current/01a_TevTF1_IntroLumi.pdf
http://www-bdnew.fnal.gov/doereview03/Current/01b_TevTF2_beambeam.pdf
http://www-bdnew.fnal.gov/doereview03/Current/01c_TevTF3_helices.pdf
http://www-bdnew.fnal.gov/doereview03/Current/01d_TevTF4_HTbb.pdf

2. Issues for Antiproton Stacking and Cooling, D. McGinnis, June, 2003.

http://www-bdnew.fnal.gov/doereview03/Current/02_Pbar_stacking_cooling.pdf

Subproject Technical Status and Plans

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